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Vision and Touch: Testing the Ramachandran Mirror Box

Christopher B. Robichaux
Northern Michigan University

VISION AND TOUCH: TESTING THE RAMACHANDRAN MIRROR BOX

By

Christopher B. Robichaux

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This thesis by Christopher B. Robichaux is recommended for approval by the student's thesis committee in the Department of Psychology and by the Dean of Graduate Studies.

Committee Chair: Dr. Charles Leith Date

First Reader: Dr. Harry Whitaker Date

Second Reader: Dr. Mitchell Klett Date

Department Head: Dr. Sheila Burns Date

Dean of Graduate Studies: Dr. Cynthia Prosen Date

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NAME: Robichaux, Christopher B.

DATE OF BIRTH: September 15, 1981

ABSTRACT

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A fundamental question in the field of psychology is how humans perceive the world around them. Particular emphasis has been placed on the idea that, when sensory systems are placed in conflicting circumstances; the visual system dominates the haptic (touch) sensory system in the creation of a person's perceptions. Scientists have used a variety of methods to research this idea, by using distortion lenses and virtual simulations on advanced computer systems. These previous studies have failed to provide a convincing illusory sensory experience or have been prohibitively expensive. This study seeks to use a simple Ramachandran Mirror Box (RMB), a device that has the potential to provide the required illusory experience, to test the differences between the visual and haptic (touch) sensory systems. The findings suggest human perception is pulled towards the visual sensory system in some conditions and shows the viability of the RMB as a perceptual testing apparatus.

DEDICATION

This thesis is dedicated to my mom and dad, Roger and Janet, without whom none of this would have been possible.

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This thesis follows the format prescribed by the *APA Style Manual* and the Department of Psychology

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INTRODUCTION

George Berkeley (1685 – 1753) studied some of the scientific works of his era, such as Issac Barrow's *Optics Lectures*, with a critical eye. Berkeley's concern was not with the mechanism of sight, as Barrow's was, but rather with the human *perception* of sight. Berkeley believed human thoughts are *Ideas*; and it is with these *Ideas* we relate to those objects around us (Berkeley, 1709). For instance, when one looked at an apple the person perceived the *Ideas* of round, red, fruit, stem, and so forth which all relate to the *Idea* of an apple. Berkeley noted the blind, despite not being able to see the apple, were still able to identify and perceive the apple through their other senses (Berkeley, 1709). Further, sight can be tricked with optical illusions and could be completely wrong in regards to distance, color, and other, then subjective, categories. Therefore, Berkeley reasoned, those *Ideas* we experience and identify through our haptic (or touch) system are more real, than those we experience through sight (Berkeley, 1709). Berkeley published his first major philosophical work *An Essay Towards A New Theory Of Vision* in 1709. Almost 200 years later, psychologists still probe the same questions that Berkeley concerned himself with: How do humans perceive the world? Does one sensory modality override, reinterpret, or mediate our perception of other modalities? Does this mediation change how we perceive the world?

Visual and Haptic Interactions

Rock and Victor (1964) designed a study wherein a participant would observe or manipulate a block of wood. While observing the wooden block, the participant had to look through a piece of plastic that created a distorted view, causing the block to visually compress to approximately half its width. Further, to keep participants from using the features of their hands to aid in measurement, a cloth was placed between the block and the participant's hand. Participants then drew their impressions of the stimulus, or chose a wooden block that nearly matched their impression of what they had observed, selecting by visual observation, or haptic sensation. Rock and Victor concluded that vision dominated over tactile sensation as almost all of their participants chose a block significantly narrower than the stimuli presented. In another experiment, the participants would look at their hand through a distortion lens. They would then close their eyes, manipulate the wooden block, and then re-observe their hand through the lens. In the end, Rock and Victor (1964) stated "23 out of 38 of the participants tested in this way reported that the object 'felt' larger with their eyes closed." (p 595). This set of experiments has become the prototypical means of examining the visual and haptic systems on human perceptions.

The hypothesis our sense of vision dominated over our haptic system has gained support. Rock's own research continued along this vein, strengthening his initial findings (Rock, Mack, Laurence, and Hill; 1965; Rock and Harris, 1967). Outside of Rock's own lab and research assistants, work was being conducted at the University of Western Ontario by Harold Lobb. Lobb's 1965 study discovered a learning phenomenon that seemed to support Rock's hypothesis. Lobb's (1965) subjects were attempting to learn how to differentiate different shapes through either a visual (v) examination, or a haptic (h) (and closed eyed) examination of the same shape. The subject would then attempt to identify the object when represented with the stimulus through one of the two methods. This resulted in four groups, v-v, v-h, h-v, or h-h. When Lobb (1965) had the students identify the shapes, he found the v-v group far outperformed the h-h group. Further, while the subjects completed multiple trials, Lobb (1965) found those in the v-h group out-performed those in the h-v or h-h groups. However, as the trials continued, the difference between the v-h and h-v groups reduced to non-significant levels. The article goes on to suggest the difference between the v-v and h-h groups, as well as the early differences between the v-h and h-v groups, might be explained by proposing that haptic learning was slower than visual learning.

At Smith College in 1970, Robert and Martha Teghtsoonian conducted a study examining the visual and haptic ordering of wooden blocks. These wooden blocks were presented in various widths to be assigned estimated measurements as perceived by the participant. In their initial experiment, participants were instructed to assign a width measurement to each block presented to them, either visually, or, while blindfolded, haptically. Haptic participants, the study found, were close in assigning the correct width to the wooden block. Those in the visual group, however, estimated the wooden blocks to be nearly twice the width of the haptic group. This created a significant difference between the two groups as the visual participants were nearly doubling the perceived size of the blocks as opposed to the haptic group. Having tried their study with the two senses separate from one another, the Teghtsoonian's (1970) ran another study with the same procedures. This time, however, the participants were allowed to examine the blocks both haptically and visually. Once the data was compiled, the researchers found this group estimated the width of the wooden blocks as nearly 2.5 times wider than their actual measurement. This was a significantly larger difference than found with only the visual examination of the blocks in the initial study. Teghtsoonian and Teghtsoonian

(1970) declared, when both the visual and haptic system were stimulated simultaneously, the visual system preempted the haptic. One of the more interesting aspects of this study, as opposed other studies that are performed when investigating the haptic and visual system, is a lack of sensory deception. When both senses were stimulated simultaneously, no prisms were involved and a black cloth was not used to hide the participant's hand. Rather, this experimental series was conducted in a more naturalistic setting one might find in earlier psychological studies. The experimenter does not always have to "outwit" the participant or their senses. Rather, the experimenter can take a less convoluted method of testing the senses and achieve similar results to those to take a more complicated methodology.

Epp A. Miller, at George Washington University, thought Rock and Victor's (1964) visual dominance hypothesis might not be as simple as previously thought. In 1972, Miller published a series of experiments designed to examine the properties of visual and haptic interactions when the senses were in conflict and nonconflict. Further, Miller (1972) believed, since Rock and Victor (1964) only used each subject once, a degree of procedural naiveté created a mediatory variable in their study. To test this hypothesis, Miller (1972) ran a series of experiments. The first experiment involved participants doing the same experiment Rock and Victor (1964) performed, thus creating a study in which the visual and haptic systems were in conflict. These participants were tested multiple times with the same object and allowed to change their initial answer after each examination of the object. Miller (1972) expressed surprise, even after several exposures, participants continued to select the answer shape closest to what was visually presented. Essentially, the subjects ignored their haptic examination altogether. For the second experiment, participants looked down on a larger piece of wood, while, with their hands, they were asked to examine a smaller piece. In this study, the participant never saw their hand manipulating the piece of wood, creating a nonconflict experiment. In this experiment, the participants all chose answers close to the block of wood they haptically examined, never choosing an answer close to the visual stimuli. For his third study, Miller (1972) used the same apparatus as his second experiment, with the exception that the piece of wood to be haptically examined was placed on the underside of the visual wooden block stimulus, directly beneath it. Two groups were employed for this experiment; one was told the visual and haptic stimuli were two identical halves of the same object, while the control group was not informed of this. In the end, those who received the incorrect information concerning the two stimuli chose a response closer to what they perceived visually, while the control group chose an answer closer to what they perceived haptically. Through his studies, Miller (1972) showed repeated experience did not have any effect on a participant's responses. Miller (1972) believed there was a cognitive factor that mediated which sensory system gains dominance over the other.

Randolph Easton and Peter Moran also had an interest in the visual dominance over the haptic system. For their 1978 study, Easton and Moran utilized a Risley prism, which causes the viewer to see the world as curved. Participants would look through this prism at a straight metal rod. Some would be allowed to examine the rod both haptically and visually, while others were confined to one perceptual system (Easton and Moran, 1978). Participants then examined another rod through the same type of prism. This rod could be manipulated by the experimenter to be either curved up or down in its center. The objective of the participant was to determine when this curved rod was straight as the previous rod, while being confined to the one of the methods of examination. During this process, the experimenter would increase or decrease the convex or concave measurements of the rod as directed by the participant. For instance, a participant may have examined the straight rod visually, and then attempted to determine when the curved rod was straight haptically. Easton and Moran (1978) found those participants who examined the adjustable rod through only their haptic system reached a near straight orientation. However, the groups which examined the curved rod through visual or visual and haptic senses averaged at least 8.7 mm off a straight line. Given these results, Easton and Moran (1978) suggested the "…variability is attributable to competing demands on allocation of a limited attentional capacity rather than to some inherent organization of the sensory system." (Easton and Moran, 1978, p.111). As with Miller (1972), Easton and Moran (1978) are suggesting there is another variable mediating our hierarchy of perception. It is also important to note Easton and Moran (1978) do not mention if the participant was able to view their hand during the haptic inspection of the rods. However, given the experimental protocols at the time, it might be safe to assume the participants did not view their hands at any point during the experiment.

In 1981, Lederman and Abbott designed a new instrument to test the dominance of vision over tactile sensation. Utilizing a lazy-Susan table, participants could reach under a piece of black fabric and feel a piece of 60-grit sandpaper, while visually presented with a sheet of 150-grit sandpaper. Placed in three different conditions, participants were either presented with only the visual stimuli, only the tactile stimuli, or both at the same time. Participants would then choose the grit of sandpaper from a choice of 9 varying textures that most closely matched their impression of the stimuli presented. They would choose their answer through either visual observation, tactile sensation of the varying sandpaper, or both at the same time. Lederman and Abbott (1981) concluded visual and tactile sensations were equally important in the task of identifying textures. While the tasks were different, Lederman and Abbot (1981) seemed to have debunked Rock and Victor's (1964) earlier findings.

Multi-modal research

In the last decade, some researchers have reexamined Rock's earlier research. The question of visual dominance, researchers proposed, is not as simple as previously suspected. Based on an earlier study by Heshberger and Misceo (1996), Heller, Calcaterra, Green, and Brown (1999), attempted to find if sensory dominance is task dependant. They designed a box to allow participant to reach into and examine different stimuli while observing their hand through a hole at the top of the box. This hole could be fitted with a minification lens as the experimental conditions required. Heller et al. then ran participants through a series of experiments to judge the size of a square under different conditions: without knowledge of the minifying lens, with knowledge of the minifying lens and seeing it's effects on the appearance of a quarter, a square with a ruler next to it, and a square participants measured by using their thumb and index finger in a pincer motion. This design differed from previous research by allowing participants to see their hands through the minifying prism and ran participants in trial blocks, allowing for a within-subject design. While judging the size of a square by itself yielded no sensory dominance, the other conditions had different results. After being informed of the illusion and having a quarter present within the box, participants increased the magnitude of size estimates. Those that saw the square next to the ruler clearly showed visual dominance, while those that measured the square by pinching it themselves showed a tactile dominance. Heller et al. (1999) argued their results showed that the idea of a sensory dominance is an oversimplification. Rather, the dominance occurs when more attention is placed upon one sensory system over another.

This idea that dominance occurs when more attention is placed upon a sensory system appears to have some support from Lederman, Thorne, and Jones, in 1986. In this series of experiments, Lederman et al. attempted to build upon the results of Lederman and Abbott (1981) by utilizing the same lazy-Susan table, but changed the sandpaper grits for a raised-dot matrix created by a computer and etched into metal and plastic. While performing the experiments, Lederman et al. found significant differences between Experiment 1, in which participants made magnitude judgments based on “spatial density” and Experiment 4, wherein participants made judgments based on a given standard in regards to “density.” (1986). It had been decided to drop the term “spatial” due to some confusion of the term by participants (Lederman et al., 1986). However, Lederman et al. found, while participants relied heavily on visual input during Experiment 1, they had a more 50/50 reliance on visual input during Experiment 4 (1986). Further, in Experiment 2, a recreation of Lederman and Abbott’s 1981 experiment, using the raised-dot pieces did not yield the equal dominance expected. Instead, a strong haptic dominance was shown with a 73.2% haptic bias to touch. It was concluded that Experiment 2’s bias occurred because participants were asked to make judgments based on roughness, as opposed to texture in the earlier study (Lederman et al.). These seemingly semantic changes in instructions appeared to yield varying results.

They hypothesized taking “spatial” out of “spatial density” removes an implicit instruction to participants to strongly attend to visual cues.

Today, the question of multi-modal research has expanded to the electronic domain.   Computers are becoming a means by which researchers can manipulate variables with exacting detail while simultaneously recording the participant’s data. Poling, Weisenberger, and Kerwin (2003), utilized a PHANToM (SensAble Devices, Inc.), a haptic force feedback interface, to simulate a piece of material with varying gratings. A visual representation of this material was created and presented on a computer screen for the participant. Participants were presented with two different gradients and asked to judge which was rougher either visually, haptically (via the PHANToM) or visually and haptically. Poling et al. found the combined condition performed more accurately than the visual or haptic condition. While this design allows for greater control by the researchers, extraordinary materials needed to be used, such as the PHANToM, extensive coding in C++, a special toolkit, and assistance from individuals with knowledge of computer interfacing (Poling et al., 2003). Further, the computer that makes the research possible limits the design. High-end computer rendering, like the photo-realistic effects found in movies, can take months to render, thus restricting the researcher to less-than-desirable graphics to represent their materials. The force feedback interface of the PHANToM is only as good as the coding and design permits. Both of these limit the real-world generalizability of results, but may also limit the ability of the participants to give reliable results to the researchers.

One must note, except for the complex and expensive computer virtual reality, Teghtsoonian and Teghtsoonian (1970), and a few conditions of Heller et al. (1999), all of the examples of visual and haptic disparity involve hiding the hand engaged in haptic exploration from direct view. While one might understand this methodology was chosen to allow for greater experimental control, Heller et al. (1999) shows how having a visible hand does not disrupt the illusion. Rather, this hidden hand procedure takes the experimental results further from generalizability, as most people do not hide their hands from sight while engaged in haptic exploration.

Ramachandran Mirror Box

Developed in 1996 by VS Ramachandran and D. Rogers-Ramachandran, the Ramachandran Mirror Box (RMB) was used to help explore phantom limb pain and possible ways to reduce this perceived pain. To use the RMB, the participant would place his or her hand through a hole in the side of the box and look down through the top of the box. Inside, they would see their hand and its mirror image, displayed via a mirror placed parallel to their remaining limb. In a series of experiments, it appeared using the box and following several exercise over a period of time, led some patients to report a reduction or extinction of their phantom limb pain (Ramachandran & Rogers-Ramachandran, 1996).

One of the predominant theories for the causes of phantom limb pain involves the neural plasticity of the brain. When a limb amputated or lost, (eg. left arm) the neurons in the brain responsible for giving instructions and receiving information are no longer being used. After a time, other areas of the brain (like those responsible for the face or torso) begin to encroach on these unused cortical neurons and take them over. Thus, when information from your face travels to these ex-left arm neurons; they may activate other left arm neurons, which the patient may interpret as pain. Ramachandran and

Rogers-Ramachandran (1996) suggested using the RMB led to the brain reestablishing the boundaries within the patient's brain, keeping face input from activating the wrong cortical neurons.

Further studies have lent credence to Ramachandran's discoveries (Lotze, Flor, Grodd, Barbig, & Birbaumer; 2001; Ramachandran & Rogers-Ramachandran, 2000). In Lotze et al. (2001) fourteen upper-limb amputee participants and seven control participants were used in a study that used the functional Magnetic Resonance Imagining (fMRI) to obtain precise measurements of which areas in the brain activated during a series of exercises. In this study, participants would make a fist with their remaining hand and imagine making a fist with their amputated hand (Lotze et al., 2001). The amputated hand task was practiced by participants until they self-scored the task better than average on a 6-point vivid image scale. The participants then performed these tasks under an fMRI, as well as a lip-pursing task. Lotze et al. (2001) found, in those patients who reported phantom limb pain, a shift had occurred as the medial border of the lip intruded into the area of the amputated hand. Further, during the imagined hand movement exercise Lotze et al noted the fMRI, "…showed increased activation in the M1/S1 lip area contralateral to the amputation side." (Lotze et al., 2001, p 2275).

Yet, while neurologists and neuropsychologists continue to use the RMB in phantom limb studies, few have tried using the device with two-handed participants (Franz and Packman, 2004). One may find this surprising given the apparent strength of the illusion generated within the RMB. Ramachandran and Rogers-Ramachandran (1996) noted a participant named D.S. who, when attempting to move their phantom limb, remarked how the limb was " 'frozen as in a concrete block'" (Ramachandran &

Rogers-Ramachandran, 1996 p 378). However, upon looking at his limbs within the box, D.S. remarked of vivid sensations originating from the former joints and muscles within his missing arm. When Ramachandran and Rogers-Ramachandran (1996) removed the mirror, the phantom limb was frozen again. One might think, given the apparent ease by which the RMB creates a powerful illusion, that the RMB might be useful for furthering the study of visual and haptic dominance.

Hypothesis

The purpose of this study is to use an RMB, a device surprisingly simple in construction and use, as a testing apparatus in a sensation and perception experiment. Given the RMB's design, participants will be able to see their hand manipulate one type of stimulus. The hand will be reflected by the mirror, causing the participant to believe that both hands are manipulating the same stimulus. Instead, the researcher will be able to present a different stimulus to the unseen hand. Lederman and Abbott's 1981 study will provide the protocol for the design of this study. The design of the study, however, will be expanded as participants will use their right and left hands. Further, this study will not only use the 60 grit sandpaper as a visual stimuli and the 150 as the non-visual, but will also reverse this stimuli to get a counterbalanced set of data. Based upon previous experiments, two hypotheses were made, 1) Similar to Rock and Victor's original experiment, a significant number of participants will choose a grade of sandpaper that's closer to the illusory visual stimulus than that presented haptically to the hidden hand, without regard to handedness. And 2) Participants who must choose an answer in the visual only examination of the answer board will choose a grits closer to the visual stimulus and significantly different from those who are allowed tactile examination.

METHODS

Participants

In all, 120 participants were recruited, according to a protocol approved by the IRB at Northern Michigan University (HS09-276, Appendix A), and utilized in this study. Participants were either undergraduates or post-graduates from Northern Michigan University. Undergraduates will be recruited via a sign-up sheet located on the third floor of Gries Hall on the Northern Michigan University campus. These undergraduates were given experimental credit by their instructors as compensation for participation. Post-graduates were recruited by the researcher and psychology instructors. The post-graduate participants will receive no compensation. All participants were at least 18 years-old and right-handed.

Apparatus

The RMB used in this study is modified from the original RMB Ramachandran used, as it has been designed for two-handed participants and to allow a greater level of adjustability for any further experiments. The RMB is constructed out of ¼ inch Masonite.

The RMB is an 18.5’’x24’’x10’’ 5-sided box with the top open to view. In the center is a slot for the 18’’ mirror to be placed. Arm/hand holes are 5’’x5’’cut into the box 2’’ from the top, bottom, and outside edge of the box on both of the 24’’ sides. Holes on both sides of the Mirror Box enable both the researcher and participant to have their hands inside the box at the same time, and allows the device hide either hand from the participant (Figure 1).

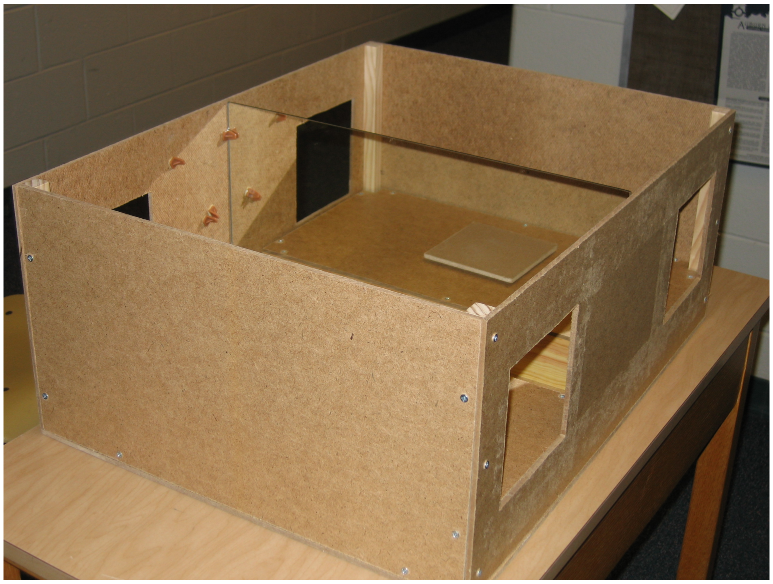

Figure 1

Shows the RMB without a cover.

A lid designed for the top of the box allows the participant look through an elliptical hole measuring 9’’x5.5’’ which starts 2.5’’ in from the side of the box and 1’’ from the side facing the participant. The size of the hole was chosen to allow the participant to see both their visible hand and its mirrored image (Figure 2). The lid covers 6’’ of the top and includes a 6’’ backstop at the end. This allows light to enter from overhead while also allowing the researcher to observe both hands at the same time (Figure 3). Two lids have been constructed to allow either the right or left hand of the participant to be hidden from sight.

Figure 2

Shows what a participant sees when looking through the opening in the RMB lid.

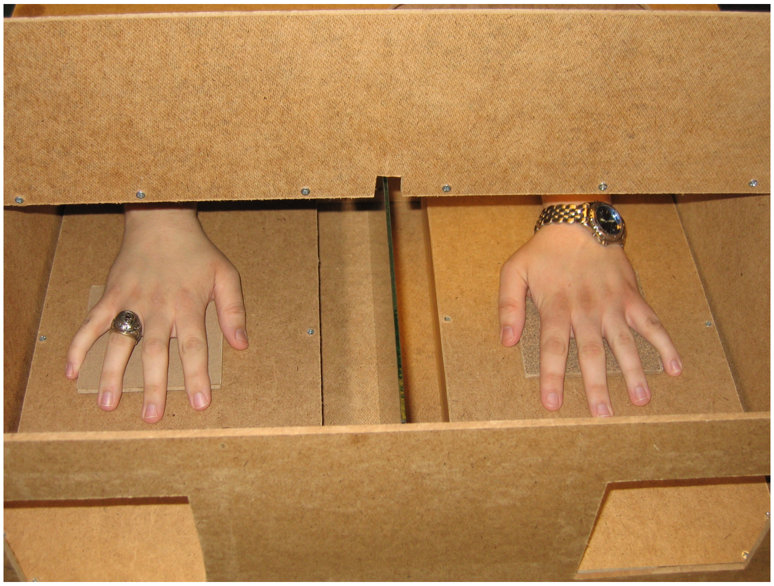

Figure 3

Shows the experimenter view. Note the differences between Figure 2 and Figure 3. Participants were not allowed to wear watches or rings during the study, and are only worn in these pictures for demonstrative purposes.

The last pieces of the RMB are two tables constructed to fit into the interior of the box. These tables measure 18’’x9.5’’ and serve several purposes. First, they act as a hand rest, allowing the participant to lay their hands inside the box without any undue discomfort. Second, 7’’ from either opening are two Velcro strips which act as the anchors for visual and tactile stimuli presented to the participant.

The visual stimuli used in this study are two pieces of aluminum oxide sandpaper, 60 and 150 grit. These stimuli have been affixed to two 4.5’’x4.5’’ pieces of Masonite via rubber cement. These squares of Masonite have Velcro attached to their bottoms, allowing them to be anchored to the tables inside the box. This use of Velcro also allows the experimenter to switch the sides the different grits of sandpaper are on, thus allowing for the visual sandpaper to be either the 150 grit, or the 60 grit.

The final apparatus to be used in this experiment is the answer board. This board has been constructed of Masonite, measures 57’’x6.25’’, and contains 9 4’’x4’’’ squares of aluminum oxide sandpaper arranged in ascending order by grit: 36, 50, 60, 80, 100, 120, 150, 180, and 220. Each square has been affixed to the board with rubber cement and contains a 1.75’’ gap between the sheets of sandpaper, as well as a 0.875’’ distance between the top and bottom of the board (Figure 4). On the back of the answer board are two hooks, designed to hold a curtain rod. Inside these hooks, a curtain rod rests with a 59"x9" piece of black cloth wrapped around it. This black cloth allows the answer board to be hidden from view of the participant (Figure 5), while raising the cloth 6" in the back to allow the researcher to see the sandpaper squares (Figure 6).

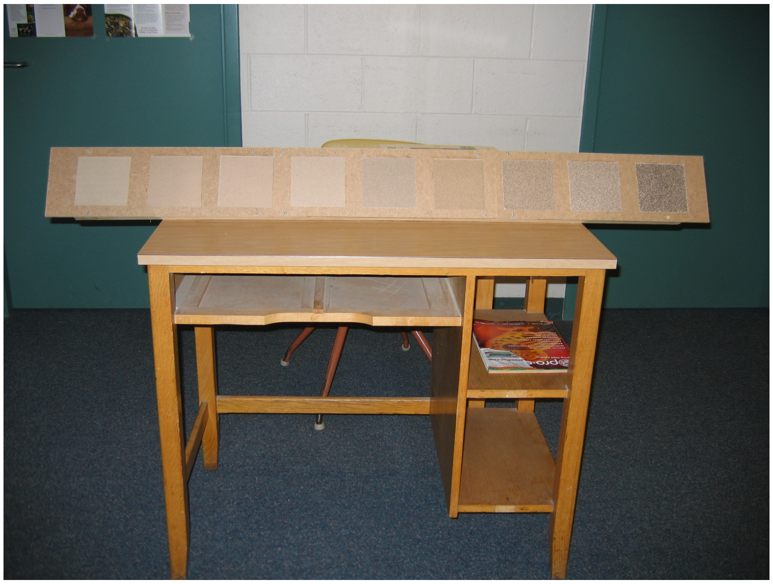

Figure 4

Shows the answer board without the black fabric curtain.

Figure 5

Shows the answer board with the black fabric curtain.

Figure 6

Shows the experimenter view of the answer board with the black fabric curtain.

Procedure

Each participant was assigned to one of twelve conditions, creating a 2x2x3 study. The first condition was which sandpaper grit was visible to the participant, either the 60 grit or the 150 grit. The second condition determined which hand was hidden from the participant, either the right, or the left. The final condition pertained to the method of choosing the dependent variable; either visually only, haptically only, or a combined condition wherein the participant could use both their visual and haptic sensory systems (please see Appendix D for a copy of the data entry sheet). Using a random number generator, the order of data collection was randomized by block. These blocks consisted of six participants in a 2x3 design based on the unseen hand and grit selection variables. The visible grit of sandpaper was randomized between a pair of blocks. This predetermination allowed the researcher to maintain an even level of data collection as the study moved forward.

The study took place in an 11' by 30' room that contained a standard chair and three tables with the apparatuses. Sunlight from windows, overhead florescent lights, and moveable canned lights provided illumination for the participants. Participants would enter the room and take a seat across from the researcher, where they would be instructed about the experiment and filled out an informed consent sheet (please see Appendix B for a copy of the informed consent sheet). Once the sheet was completed, the researcher explained the previous uses of the RMB and that an illusion was the focus of the study. The researcher would then explain a series of hand exercises the participant was to complete within the RMB (for a complete explanation of the exercises, please see Appendix C). Once the participant understood the hand exercises, they were directed to another table, where the RMB was already set-up based on the predetermined hand condition. After turning on a video recorder, the participant was instructed to spend two-minutes going through the hand exercises, with the researcher offering prompts as needed. This was to habituate the participant to the RMB, and allow them to forget there was an illusory process occurring. Once time had expired, the researcher informed the participant a piece of sandpaper was going to be placed at the bottom of the box. The participant was to examine the sandpaper while moving their hands in a mirrored fashion for as long as they felt necessary. The researcher then simultaneously placed the pieces of Masonite with the 60 grit sandpaper and the 150 grit sandpaper inside the box, affixing them to the pieces of Velcro. The placement of the sandpaper was predetermined by the visible grit condition.

Once the participant finished with examining the pieces of sandpaper, the video camera was turned off and they were directed to a third table. Here, the answer board was laid out with the black cloth hiding the answer board from the view of the participant. The researcher then instructed the participant in the method of choosing the sandpaper that most closely matched the impression of the sandpaper from their unseen hand (the researcher always referred to this hand by name). For the visual and combined conditions, the researcher would then remove the curtain rod and the black cloth from the answer board. For the haptic condition, the participants were instructed to reach underneath the cloth. The haptic and combined conditions were instructed to place their hand upon their choice and let the researcher know of their final decision, while the visual group was only permitted to point to their final answer.

Participants were then instructed back to the table with the RMB with the researcher removing the pieces of sandpaper from the Velcro strips inside the RMB. The researcher then instructed the participant to spend another two minutes going through the same hand exercises completed earlier. After the researcher turned the video camera back on, the researcher instructed the participant to examine a piece of sandpaper placed at the bottom of the box. This time, the researcher always placed the 150 grit piece of sandpaper under the visible hand, and a blank piece of Masonite, matching the sandpaper's dimensions, under the unseen hand. Once the participant was finished, the researcher asked the participant, on a scale of 1 to 7, with 1 being low and 7 being high, to rate the visual/tactile disagreement in what they just experienced. The researcher explained the question in greater detail to those participants who displayed confusion at the question, and recorded the answer.

The researcher then debriefed the participants, explaining the previous findings of research in the area of the perception of roughness. The RMB was also explained in greater detail, revealing the mirror and how the answer selected from the answer board would help to inform on the experimental question. Lastly, the researcher asked the participant not to reveal the details of the illusion to other possible participants due to the possible creation of confounding variables, and presented them with an opportunity to leave their e-mail address should the participant wish to find out the final results of the study.

Data Analysis

All data collected by the researcher was entered into a data sheet using Excel 2007. The data was then transferred to SPSS for analysis. All statistical information cited in the results section comes from information gathered via SPSS. All charts and graphs were created in Excel 2007 based on the information derived from SPSS.

For scoring purposes, in the 60-grit condition, the sandpaper grits were assigned a numerical value (36 =1, 50=2, 60=3, etc.). In the 150-grit condition, the answer scores were reversed. This kept the grit visually presented to the visible hand at a score of 3 and the grit haptically presented to the hidden hand behind the mirror at a score of 7.

RESULTS

In this study, data was collected from 122 people (43 male, 79 female). The final 2 participants were excluded from the data analysis to maintain equal numbers in all cells of the 2x3x2 design. A total of 60 participants were placed in the 60 grit condition, and the same number in the 150 grit condition. These 60 participants were spread evenly throughout the three choice conditions, yielding 20 participants per group. Finally, within each choice condition 10 participants were assigned to the left hand unseen condition, and 10 participants were assigned to the right hand unseen condition.

A 2x3x2 analysis of variance (ANOVA) was performed to find any main effects or interaction effects between the experimental conditions (Table 1). Main effects were found in the Visual Grit condition, $F(1,1) = 19.550$, $p<.000$, and the Grit Selection condition, $F(1,2) = 7.737$, $p=.001$. The Unseen Hand condition was not found to be significant ($p=.133$). No interaction effects between the experimental conditions were found to be significant at the ($p=.120$).

Source	Type III Sum of Squares	df	Mean Square	f	Sig	Partial Eta Squared
Visual Grit	44.408	1	44.408	19.550	0.000	0.461
Grit Selection	35.150	2	17.575	7.737	0.001	0.120
Unseen Hand	5.208	1	5.208	2.295	0.133	0.016
Visual Grit * Grit Selection	9.817	2	4.908	2.161	0.120	0.037
Visual Grit * Unseen Hand	1.008	1	1.008	0.444	0.506	0.002
Grit Selection * Unseen Hand	4.017	2	2.008	0.885	0.416	0.007
Visual Grit * Grit Selection * Unseen Hand	3.617	2	1.808	0.797	0.453	0.006
Error	245.100	114	2.271			
Total	348.325	119				

Table1

Shows a 2x3x2 ANOVA of the three independent variables.

In the 60-grit condition, it was found the Visual group ($M=3.55$, $SD=1.276$) varied greatly from the Haptic group ($M=5.55$, $SD=1.761$). The Combined condition

(M=4.30, SD=1.302) seemed to split the difference between the Visual and the Haptic. Looking at the 150-grit condition, we found a similar trend in that the Visual group (M=5.45, SD=1.791) and the Haptic group (M=6.05, SD=1.317) setting the outer bounds, while the Combined condition (M=5.55, SD=1.504) fell in-between (Table 2 and Figure 7).

Visual Grit	Grit Selection	Mean	STD
60-Grit	Visual	3.55	1.276
	Haptic	5.55	1.761
	Combined	4.30	1.302
150-Grit	Visual	5.45	1.791
	Haptic	6.05	1.317
	Combined	5.55	1.504

Table 2

Shows the Means and STD grit selection of each choice condition and grit condition.

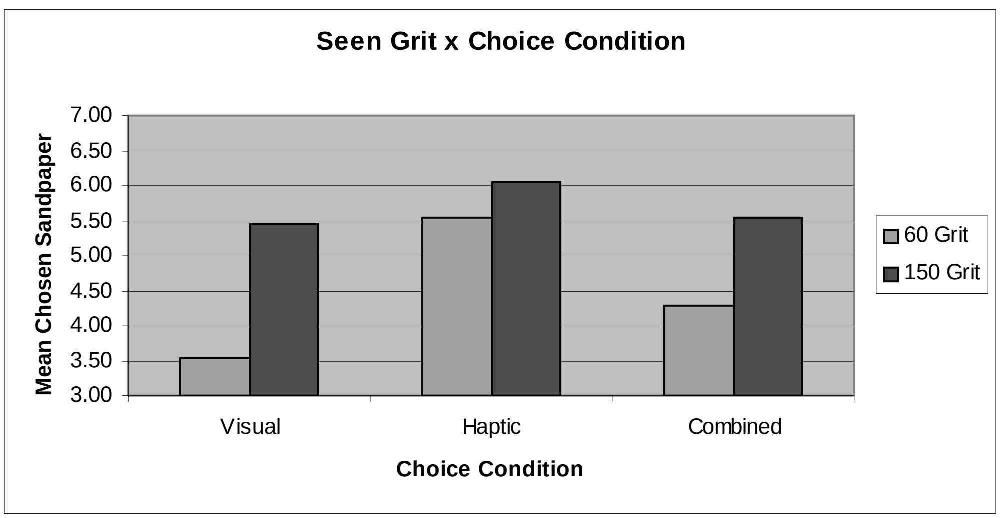

Figure 7

Shows the Means of each choice condition by seen grit. In this figure, 3 is the visual stimulus, and 7 is the unseen stimulus was explored haptically by the participants

To examine the first hypothesis, Tukey's HSD post-hoc test was used to examine any significant differences between the choice conditions. It was found the Visual group (M=4.50, SD=1.812) differed significantly from the Haptic group (M=5.80, p=1.556), p=0.001. Also, the Haptic group significantly differed from the Combined group

(M=4.92, SD=1.526), p=0.029. However, significant differences were not found between the Visual and Combined group at the p<.05 level (Table 3). These results support the first and second hypotheses.

					95% Confidence Interval	
Grit Selection	Grit Selection	Mean Difference	Std. Error	Sig	Lower Bound	Upper Bound
Visual	Haptic	-1.30*	0.337	0.001	-2.10	-0.50
Visual	Combined	-0.42	0.337	0.420	-1.23	0.38
Haptic	Combined	0.88*	0.337	0.029	.07	1.68

Based on observed means.
The error term is Mean Square(Error) = 2.271
*. The mean difference is significant at the 0.05 level.

Table 3
Shows the results of a Tukey's HSD performed on the Choice Conditions

However the largest main effect of grit in the 2x3x2 ANOVA was important to in understanding the outcome. It is interesting to note when the choice condition of the shown grits was examined separately, as opposed to collapsed together, a slightly different result was found. In the 60-grit condition, a significant effect was found between the choice conditions using a one-way ANOVA, $F(1,2)=9.531$, $p<0.000$ (Table 4) confirming the results of the 2x3x2 ANOVA performed earlier. However, in the counterbalancing 150-grit condition, this effect was not found, $F(1,2)=0.861$, $p=0.428$ (Table 5).

Source	Type III Sum of Squares	df	Mean Square	f	Sig	Partial Eta Squared
Grit Selection	4.083	2	20.417	9.531	0.001	0.251
Error	122.100	57	2.142			
Total	162.933	59				

Table 4
Shows a one-way ANOVA of the Choice Condition in the 60-grit condition.

Source	Type III Sum of Squares	df	Mean Square	f	Sig	Partial Eta Squared
Grit Selection	4.133	2	2.067	0.861	0.428	0.029
Error	136.850	57	2.401			
Total	140.983	59				

Table 5

Shows a one-way ANOVA of the Choice Condition in the 150-grit condition.

Lastly, the Surprise Scale was examined, testing it with a 2x3 ANOVA to find any main effects or interaction effects between choice condition or shown grit. No significant effects at the $p<.005$ level were found (Table 6). Looking at the descriptive data of the groups, all of the groups rated the surprise of a large visual/haptic disparity at about 5 on a 1 to 7 point scale, with 7 being the highest possible score.

Source	Type III Sum of Squares	df	Mean Square	f	Sig
Visual Grit	1.008	1	1.008	0.393	0.532
Grit Selection	1.117	2	0.558	0.217	0.805
Visual Grit * Grit Selection	8.017	2	4.008	1.560	0.215
Error	292.850	114	2.569		
Total	302.992	119			

Table 6

Shows a 2x3 ANOVA of Seen Grit by Choice Condition with the responses on the Surprise Scale as a dependant variable.

DISCUSSION

As Rock and Victor found in their 1964 study, the data suggests vision does dominate our perception in this task. The significant differences found between the Combined group and the Haptic group shows the participants visual system playing a significantly large role in their answer selection. The second hypothesis that those in the Visual group would choose an answer closer to the visual stimuli was supported by the data.

This study attempted to replicate Lederman and Abbott's 1981 study while also building upon it. In this endeavor, it was decided to counter-balance the seen grit of sandpaper, which created an interesting result. The significant differences found between the Visual selection, Haptic selection, and Combined selection groups in the 60-grit condition, does not appear in the 150-grit condition when those data are examined separately. The 150-grit condition shows selections that are pulled towards the haptically presented grit across all selection conditions including the visual only selection. It may be the sensations of rubbing a 60-grit sandpaper are more robust than those of a 150-grit sandpaper. When shown an answer board, the participants may have looked (or felt) the finer grits of sandpaper and remembered the unseen hand as being rougher. Note the Surprise test pitted the visual 150-grit against a smooth piece of Masonite and obtained clear evidence of awareness of such a large discrepancy. Care was taken within this study to avoid the possible linguistic cues Lederman et al. found in their 1986 experiments and the attentional shifts found by Heller et al. (1999). When the researcher had to make mention of the different sensory systems, both would be mentioned in an attempt to give the systems equal weight. When the participant was asked to choose from the answer board, they were instructed to "…choose the sandpaper that most closely matches the impression…" of the sandpaper from their unseen hand (Appendix C). However, it is possible an attentional shift did occur in the 150-grit condition. Perhaps pitting the 150-grit against a rougher grit also elicited a surprise and unintentionally diverted the participant's attention to the haptic side of the experimental experience. Clearly, a psychologically scaled set of roughness stimuli would help sort this problem.

Another possible explanation for the differences between the 60-grit and 150-grit concerns the appearance of the sandpaper grits. The aluminum oxide sandpaper grits are mostly tan in color, with the rougher grits having specks of black and the smoother grits appearing closer to a light sandstone. It may be that the 150-grit sandpaper is not as visually stimulating as the 60-grit sandpaper. This could have caused the participant's attention to shift away from a visually dull stimulus to a more interesting haptic stimulus. This problem could be overcome if the sandpapers were painted a color in which sandpaper does not usually appear (e.g., lime-green, canary yellow, etc.) The paint would have to be very fine and thin so it would not interfere with the texture of the sandpaper grits. However, this could eliminate a possible visual attentional shift from occurring.

Further attempts to improve upon Lederman and Abbott's study included the left-hand unseen condition. When Lederman and Abbott first did the study, participants used their preferred hand to examine the stimulus (1981). It was thought, at the time the current study was proposed, that participants might have reduced accuracy in identifying the unseen grit of sandpaper with their non-dominant hand. The data, however, did not support this as no significant differences were found between the right-handed and left-handed trials.

One might raise the question of whether the illusion generated by the RMB is a true illusion, and if the participants would be able to tell if the 60 and 150 grits of sandpaper were different without this effect. To test this, a pilot study was performed wherein 12 participants, 6 in each Seen Grit condition, were asked to participate in the experiment as everyone else did. After giving an answer to the Surprise Scale, one additional task was asked of them. These 12 participants placed their hands back inside the box, closed their eyes, and told the experimenter if the two grits of sandpaper inside the box were the same or different. All 12 participants identified the sandpaper grits as being different. One participant asked if these had been the same grits had been used in the earlier portion of the study. When it was explained these grits had been used earlier and were placed under the same hand as in the earlier section, the participant was very shocked. The participant then explained how she had believed both hands examined the same grit of sandpaper while her eyes were open. Yet, with her eyes closed and no longer under the illusory effects of the RMB, it was simple to tell the two pieces of sandpaper were different from each other. This example, combined with the above average rating on the Surprise Scale, suggests the choices participants made during the experiment were the result of their illusory perception of their experiences, and not just an inability to discern the differences in sandpaper.

Future Research

This study has shown the RMB as a viable option for those that wish to present disparate visual and haptic stimuli. While it does not have the exactness of a computer model, it's also not as expensive nor does it require the technical expertise the computer systems require. It is also closer to a real world model than what is currently available via computers.

Future research should use carefully scaled textures to examine the size and importance of the apparently unidirectional illusion revealed by the counterbalance 150-grit condition. Also, it would be useful to have a no-illusion control group. This would allow experimenters to establish the accuracy of perception without conflicting information. This could be done by simply removing the mirror from the RMB, allowing participants to see their real hands while keeping all of the other procedures the same. With this unconflicted anchor point, one could make solid estimates of the conflicting information and assign relative weights to two difference senses under different conditions of attention. In this application the RMB would provide more exactly parallel experiences between experimental and control groups than would ever be possible using the classic hidden hand procedures.

Further areas of possible research include making changes to the RMB and answer board. The RMB could be modified to allow the use of a camera. This could allow researchers to closely examine the movement rates of participant's hands to see if there are any differences in the rate of examination. Also, a periscope rig could be built to aid the participant in viewing their hand and its mirrored image. Currently, participants have to lean to the side to view both their hand and its mirrored image. A periscope rig could be placed in the middle and, with a reflective mirrors, allow participants to sit comfortably in the middle of the RMB while being presented from the same view as previous participants experienced while leaning to the side. The answer board could also be modified to allow greater experimental control. In its current configuration, the possible selection sandpapers are arranged in scaled order. It would be possible for researchers to randomize the order of the selection sandpapers by creating 9 individual pieces of Masonite for the sandpapers to be mounted upon. This modification could prevent participants from making intuitive jumps, as may have happened in the 150-grit condition, when selecting their answers.

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APPENDIX A

Northern Michigan University

Continuing Education
1401 Presque Isle Avenue
Marquette, MI 49855-5301

June 30, 2009

TO: Christopher B. Robichaux
Psychology

FROM: Cynthia A. Prosen, Ph.D.
Dean of Graduate Studies & Research CP

RE: Human Subjects Proposal # HS09-276

"Vision and Touch"

The Internal Review Board (IRB) has reviewed your proposal and has given it final approval. To maintain permission from the Federal government to use human subjects in research, certain reporting processes are required. As the principal investigator, you are required to:

A. Include the statement "Approved by IRB: Project # (listed above) on all research materials you distribute, as well as on any correspondence concerning this project.

B. Provide the Internal Review Board letters from the agency(ies) where the research will take place within 14 days of the receipt of this letter. Letters from agencies should be submitted if the research is being done in (a) a hospital, in which case you will need a letter from the hospital administrator; (b) a school district, in which case you will need a letter from the superintendent, as well as the principal of the school where the research will be done; or (c) a facility that has its own Institutional Review Board, in which case you will need a letter from the chair of that board.

C. Report to the Internal Review Board any deviations from the methods and procedures outlined in your original protocol. If you find that modifications of methods or procedures are necessary, please report these to the Human Subjects Research Review Committee before proceeding with data collection.

D. Submit progress reports on your project every 12 months. You should report how many subjects have participated in the project and verify that you are following the methods and procedures outlined in your approved protocol.

E. Report to the Internal Review Board that your project has been completed. You are required to provide a short progress report to the Internal Review Board in which you provide information about your subjects, procedures to ensure confidentiality/anonymity of subjects, and the final disposition of records obtained as part of the research (see Section II.C.7.c).

F. Submit renewal of your project to the Internal Review Board if the project extends beyond three years from the date of approval.

It is your responsibility to seek renewal if you wish to continue with a three-year permit. At that time, you will complete (D) or (E), depending on the status of your project.

kjm

E-mail: conteduc@nmu.edu ■ Web site: www.nmu.edu/ce

Northern
Michigan
University

Continuing Education
1401 Presque Isle Avenue
Marquette, MI 49855-5301

August 12, 2009

TO: Christopher B. Robichaux
Psychology

FROM: Cynthia A. Prosen, Ph.D. CP
Graduate Studies, Research & Continuing Education

RE: Modications of Human Subjects Proposal # HS09-276
"Vision and Touch"

Your request for modifications to your Human Subjects Proposal (see above mentioned project) has been approved. Please include your proposal number on all research materials and on any correspondence regarding this project.

kjm

cc: Randy Jensen

Solitaire1981@gmail.com

E-mail: conteduc@nmu.edu ■ Web site: www.nmu.edu/cc

APPENDIX B

Informed Consent

Researcher
Christopher B. Robichaux
315 Gries Hall
Marquette, MI
(906) 227-2625
crobicha@nmu.edu

The proposed study seeks to examine the relationship between the visual sensory system and haptic (touch) system as it relates to the perception of roughness in sandpaper. You will be randomly placed into a left or right handed condition. The handed condition refers to which hand with which you will be asked to match your impression on an answer board. All groups will spend 5 minutes adjusting to the Mirror Box through several activities led by the experimenter. Once this adjustment time is complete, participants will be asked to rub the piece of sandpaper at the bottom of the Mirror Box. After this, participants will then choose a type of sandpaper that most closely matches their impressions of the hand selected by the experimenter. This selection will be done either visually only, haptically only, or visually and haptically. In the visual and haptic examination, the participant will be allowed to touch and otherwise examine the sandpapers on the answer board. This study will last no more than 15 minutes. All answers will be recorded by the experimenter along with your gender. At no point will names or ages be associated with the data collected. Also, your hands will be videotaped throughout the experiment. This is only to ensure that the experimental protocols are met. Neither your face nor name will be mentioned or shown on this tape.

Upon completion of the study, all data will be placed in a secure and locked location. After a period of seven years, all data will be destroyed.

At any point in the study, you will be allowed to withdraw from the study. There will be no consequences for leaving the study before its completion. If you choose to leave, you will still receive course credit.

It is possible that some muscle cramping and eye strain may occur, but it will be no worse than examining a bathroom mirror. The possible benefits of this research include the expansion of our knowledge of our sensory systems and the perceptions humans' experience.

Participants who complete the study may be given credit as decided by their instructors.

Questions concerning the study or its results may be directed to the principal researcher listed above. Questions concerning research participant's rights may be directed to Dr. Cynthia A. Prosen, 401 Cohodas, Northern Michigan University, Marquette, MI. (906) 227-2300, cprosen@nmu.edu.

By affixing my signature, I have read and understood the above. I give my consent to being videotaped in the course of this experiment. I declare that I have been informed about the proposed experiment; the risks involved, and give my consent to participate in the study.

Signature Date

APPENDIX C

Script for Visual Only Group

RESEARCHER: Good morning/afternoon, and thank you for being interested in participating in our study. We are interested in studying how our visual sensory system and our haptic, or touch, sensory system combine to create our perception of roughness. Before the study is explained in greater detail, you must first fill out the informed consent sheet. Please read the form in its entirety so you will understand your rights as a participant and the possible risks involved with this study. Also, please understand that you will be agreeing to be videotaped during the duration of this study. This tape will only be used for making sure that the correct protocol was maintained through this study. At the end of the study, all tapes will be erased.

WAIT FOR FORMS TO BE SIGNED

Thank you for agreeing to participate in our study. The research you are participating in involves a modified version of the Ramachandran Mirror Box. This device was originally designed to help amputee patients with their phantom limb pain. Our experiment is examining different aspects of the illusion generated by the box. To start with, we are going to have you perform a sequence of mirrored hand exercises. First, let me show you what we mean by that. (**Begin moving hands palm up together, palm down together, and so forth**) Notice that as my hands are moving, they are mirroring each other. As I close my fist, I work from the thumbs on both hands, and then end with the pinky. Now, you try. (**Wait for participant to replicate hand movements.**

Provide prompts and adjustments as necessary). Very Good. For this experiment, you will need to do several of these hand exercises for a few minutes. The exercises are as thus: **(Do hand motions while going through exercises).** We start with the palms of our hands facing downwards. We then slowly rotate them until the palms are facing upwards, and then rotate them back down. We then close our fist and repeat the motion. Next, we open our hands and rotate until our palms are facing the opposite hands. We then rotate them till the palms face upwards, then downwards, and then bring them to our starting position. We again close our fists and repeat the previous motions. Lastly, we start with our palms facing upwards, and repeat the motions we did in the previous sequences starting with an open hand, and then a closed fist. Again, we face our palms to the opposite hand and start with turning our hands downwards and then up, and repeat the motion with a closed fist. These will be the exercises that we will do inside the mirror box. Now, you try (**Watch participant go through each motion, make sure that their hands move at the same rate throughout the exercise).** Good. Now, this is device that we will be using for this study. Please remove any rings or watches that you may have. Please place both of your hands inside the box. Then, adjust the chair and your position so that you may observe both of your hands through the opening in the lid. (**Wait for the participant to adjust themselves**) We will now spend 2 minutes going through a series of exercise within this box. We will be using the same exercise we just practiced. Please make sure to observe both of your hands as we go through these exercises. (**Start video recorder. Have subject mimic the same exercise as before for a duration of 2 minutes).**

Very Good. Now I am going to place a piece of sandpaper at the bottom of the box. Once I have finished giving instructions, you will have as long as you'd like to examine this stimulus. When examining the sandpaper, please remember to move both hands in a mirrored fashion, like we've been practicing for the past several minutes. You will have as long as you'd like to examine the sandpaper. Once you've finished, you may remove your hands from the box. (**Place both sandpaper pieces on the Velcro strips, according to block information.)** You may now examine the sandpaper. (**Let participant examine the sandpaper as long as they'd like. Once their hands have been removed from the box, turn off the video recorder, remove the sandpaper pieces from the box, and remove the mirror box from the table. Present participant the answer board by laying it on the table in front of them. Make sure that the board is presented with the rougher grits of sandpaper on your (experimenter's) right)**.

Please do not touch the board until you have heard all of the instructions. Now that you've finished examining the sandpaper, please chose the sandpaper that most closely matches the impressions of the sandpaper from your (**NONVISIBLE)** left/right hand. You may only examine the sandpapers visually. Once you have decided on an answer, please point to it. (**Remove cover from the board and allow the participant to examine it. When participant points to a piece of sandpaper, touch the sandpaper and make sure that is their selection. Record the answer on the score sheet, along with their gender and block information. Remove the answer board and bring the mirror box back on the table.)**

We will now be doing a second exercise. Again, please adjust the chair and your position so that you may observe both of your hands through the opening in the lid. (**Wait for the participant to adjust themselves**) We will go through the same exercises we did a little while ago for another period of 2 minutes. If you need a refresher on the exercises, please let me know. Let us begin (**Turn video recorder back on and watch the participant perform the exercises for 2 minutes.)** Good. As before, I place a piece of sandpaper inside of the box for you to examine. As before, you will have as long as you'd like to examine the sandpaper. When you have finished, please remove your hands from the box. (**Place the stimuli on the Velcro strips. 150 grit on the seen hand, and the blank board on the unseen.)** You may now examine the sandpaper. (**Let participant examine the sandpaper as long as they'd like. Once their hands have been removed from the box, turn off the video recorder.)** On a seven-point scale, with 1 being not very and 7 as extremely, how would you rate the visual/tactile disagreement in what you just experienced? **(Record their answer on the score sheet and move to DEBREIFING script.)**

Script For Visual and Haptic Group

RESEARCHER: Good morning/afternoon, and thank you for being interested in participating in our study. We are interested in studying how our visual sensory system and our haptic, or touch, sensory system combine to create our perception of roughness. Before the study is explained in greater detail, you must first fill out the informed consent sheet. Please read the form in its entirety so you will understand your rights as a participant and the possible risks involved with this study. Also, please understand that you will be agreeing to be videotaped during the duration of this study. This tape will only be used for making sure that the correct protocol was maintained through this study. At the end of the study, all tapes will be erased.

WAIT FOR FORMS TO BE SIGNED

Thank you for agreeing to participate in our study. The research you are participating in involves a modified version of the Ramachandran Mirror Box. This device was originally designed to help amputee patients with their phantom limb pain. Our experiment is examining different aspects of the illusion generated by the box. To start with, we are going to have you perform a sequence of mirrored hand exercises. First, let me show you what we mean by that. (**Begin moving hands palm up together, palm down together, and so forth**) Notice that as my hands are moving, they are mirroring each other. As I close my fist, I work from the thumbs on both hands, and then end with the pinky. Now, you try. (**Wait for participant to replicate hand movements. Provide prompts and adjustments as necessary**). Very Good. For this experiment, you will need to do several of these hand exercises for a few minutes. The exercises are as thus: **(Do hand motions while going through exercises).** We start with the palms of our hands facing downwards. We then slowly rotate them until the palms are facing upwards, and then rotate them back down. We then close our fist and repeat the motion. Next, we open our hands and rotate until our palms are facing the opposite hands. We then rotate them till the palms face upwards, then downwards, and then bring them to our starting position. We again close our fists and repeat the previous motions. Lastly, we start with our palms facing upwards, and repeat the motions we did in the previous sequences starting with an open hand, and then a closed fist. Again, we face our palms to the opposite hand and start with turning our hands downwards and then up, and repeat the motion with a closed fist. These will be the exercises that we will do inside the mirror box. Now, you try (**Watch participant go through each motion, make sure that their hands move at the same rate throughout the exercise).** Good. Now, this is device that we will be using for this study. Please remove any rings or watches that you may have. Please place both of your hands inside the box. Then, adjust the chair and your position so that you may observe both of your hands through the opening in the lid. (**Wait for the participant to adjust themselves**) We will now spend 2 minutes going through a series of exercise within this box. We will be using the same exercise we just practiced. Please make sure to observe both of your hands as we go through these exercises. (**Start video recorder. Have subject mimic the same exercise as before for a duration of 2 minutes).**

Very Good. Now I am going to place a piece of sandpaper at the bottom of the box. Once I have finished giving instructions, you will have as long as you'd like to examine this stimulus. When examining the sandpaper, please remember to move both hands in a mirrored fashion, like we've been practicing for the past several minutes. You will have as long as you'd like to examine the sandpaper. Once you've finished, you may remove your hands from the box. (**Place both sandpaper pieces on the Velcro strips, according to block information).** You may now examine the sandpaper. (**Let participant examine the sandpaper as long as they'd like. Once their hands have been removed from the box, turn off the video recorder, remove the sandpaper pieces from the box, and remove the mirror box from the table. Present participant the answer board by laying it on the table in front of them. Make sure that the board is presented with the rougher grits of sandpaper on your (experimenter's) right)**.

Now that you've finished examining the sandpaper, please chose the sandpaper that most closely matches the impressions of the sandpaper from your (**NONVISIBLE)** left/right hand. You may examine the sandpapers both visually and through touch. Once you have decided on an answer, please place your hand upon it and let me know you've reached a decision. (**Remove cover from the board and allow the participant to examine it. When participant points to a piece of sandpaper, touch the sandpaper and make sure that is their selection. Record the answer on the score sheet, along with their gender and block information. Remove the answer board and bring the mirror box back on the table.)**

We will now be doing a second exercise. Again, please adjust the chair and your position so that you may observe both of your hands through the opening in the lid. (**Wait for the participant to adjust themselves**) We will go through the same exercises we did a little while ago for another period of 2 minutes. If you need a refresher on the exercises, please let me know. Let us begin (**Turn video recorder back on and watch the participant perform the exercises for 2 minutes.)** Good. As before, I place a piece of sandpaper inside of the box for you to examine. As before, you will have as long as you'd like to examine the sandpaper. When you have finished, please remove your hands from the box. (**Place the stimuli on the Velcro strips. 150 grit on the seen hand, and the blank board on the unseen.)** You may now examine the sandpaper. (**Let participant examine the sandpaper as long as they'd like. Once their hands have been removed from the box, turn off the video recorder.)** On a seven-point scale, with 1 being not very and 7 as extremely, how would you rate the visual/tactile disagreement in what you just experienced? **(Record their answer on the score sheet and move to DEBREIFING script.)**

Script For Haptic Group

RESEARCHER: Good morning/afternoon, and thank you for being interested in participating in our study. We are interested in studying how our visual sensory system and our haptic, or touch, sensory system combine to create our perception of roughness. Before the study is explained in greater detail, you must first fill out the informed consent sheet. Please read the form in its entirety so you will understand your rights as a participant and the possible risks involved with this study. Also, please understand that you will be agreeing to be videotaped during the duration of this study. This tape will only be used for making sure that the correct protocol was maintained through this study. At the end of the study, all tapes will be erased.

WAIT FOR FORMS TO BE SIGNED

Thank you for agreeing to participate in our study. The research you are participating in involves a modified version of the Ramachandran Mirror Box. This device was originally designed to help amputee patients with their phantom limb pain. Our experiment is examining different aspects of the illusion generated by the box. To start with, we are going to have you perform a sequence of mirrored hand exercises. First, let me show you what we mean by that. (**Begin moving hands palm up together, palm down together, and so forth**) Notice that as my hands are moving, they are mirroring each other. As I close my fist, I work from the thumbs on both hands, and then end with the pinky. Now, you try. (**Wait for participant to replicate hand movements. Provide prompts and adjustments as necessary**). Very Good. For this experiment, you will need to do several of these hand exercises for a few minutes. The exercises are as thus: **(Do hand motions while going through exercises).** We start with the palms of our hands facing downwards. We then slowly rotate them until the palms are facing upwards, and then rotate them back down. We then close our fist and repeat the motion. Next, we open our hands and rotate until our palms are facing the opposite hands. We then rotate them till the palms face upwards, then downwards, and then bring them to our starting position. We again close our fists and repeat the previous motions. Lastly, we start with our palms facing upwards, and repeat the motions we did in the previous sequences starting with an open hand, and then a closed fist. Again, we face our palms to the opposite hand and start with turning our hands downwards and then up, and repeat the motion with a closed fist. These will be the exercises that we will do inside the mirror box. Now, you try (**Watch participant go through each motion, make sure that their hands move at the same rate throughout the exercise).** Good. Now, this is device that we will be using for this study. Please remove any rings or watches that you may have. Please place both of your hands inside the box. Then, adjust the chair and your position so that you may observe both of your hands through the opening in the lid. (**Wait for the participant to adjust themselves**) We will now spend 2 minutes going through a series of exercise within this box. We will be using the same exercise we just practiced. Please make sure to observe both of your hands as we go through these exercises. (**Start video recorder. Have subject mimic the same exercise as before for a duration of 2 minutes).**

Very Good. Now I am going to place a piece of sandpaper at the bottom of the box. Once I have finished giving instructions, you will have as long as you'd like to examine this stimulus. When examining the sandpaper, please remember to move both hands in a mirrored fashion, like we've been practicing for the past several minutes. You will have as long as you'd like to examine the sandpaper. Once you've finished, you may remove your hands from the box. (**Place both sandpaper pieces on the Velcro strips, according to block information).** You may now examine the sandpaper. (**Let participant examine the sandpaper as long as they'd like. Once their hands have been removed from the box, turn off the video recorder, remove the sandpaper pieces from the box, and remove the mirror box from the table. Present participant the answer board by laying it on the table in front of them. Make sure that the board is presented with the rougher grits of sandpaper on your (experimenter's) right)**.

Now that you've finished examining the sandpaper, please chose the sandpaper that most closely matches the impressions of the sandpaper from your (**NONVISIBLE)** left/right hand. You may examine the sandpapers through touch only. You will reach underneath the cloth and examine the 9 pieces of sandpaper. Once you have decided on an answer, please place your hand upon it and let me know you've reached a decision. (**When participant points to a piece of sandpaper, touch the sandpaper and make sure that is their selection. Record the answer on the score sheet, along with their gender and block information. Remove the answer board and bring the mirror box back on the table.)**

We will now be doing a second exercise. Again, please adjust the chair and your position so that you may observe both of your hands through the opening in the lid. (**Wait for the participant to adjust themselves**) We will go through the same exercises we did a little while ago for another period of 2 minutes. If you need a refresher on the exercises, please let me know. Let us begin (**Turn video recorder back on and watch the participant perform the exercises for 2 minutes.)** Good. As before, I place a piece of sandpaper inside of the box for you to examine. As before, you will have as long as you'd like to examine the sandpaper. When you have finished, please remove your hands from the box. (**Place the stimuli on the Velcro strips. 150 grit on the seen hand, and the blank board on the unseen.)** You may now examine the sandpaper. (**Let participant examine the sandpaper as long as they'd like. Once their hands have been removed from the box, turn off the video recorder.)** On a seven-point scale, with 1 being not very and 7 as extremely, how would you rate the visual/tactile disagreement in what you just experienced? **(Record their answer on the score sheet and move to DEBREIFING script.)**

DEBRIEFING

RESEARCHER: Thank you for participating in our study. As we told you earlier, we are researching the relationship between our visual and haptic sensory systems. Previous research has not clearly shown if the visual or haptic system dominates our perception of roughness or if there is a cross-modal interaction between the two systems. This device that we are using is called the Ramachandran Mirror Box. Traditionally, it has been used to help amputee patients with phantom limb pain. For this study, we modified it to allow two-handed people such, such as yourself, to use this box for sensory experiments. (**Remove the top from the Box, showing the mirror and sandpaper)**. When you used the box, your (**unseen hand)** was hidden from view. By choosing a grit of sandpaper from the answer board, we will be able to reach new insights into how our sensory systems interact with each other. This is a novel use for this device, and also differs from pervious experiments by allowing participants, such as yourself, to see an illusion of their hand to examine one type of stimulus, while actually being presented with another. Given the nature of this experiment, please do not tell others about the illusion, as this will create confounding variables in our data. If you would like to receive the results of our study, please leave your e-mail address on this form. Again, thank you for your time.

APPENDIX D

Thesis Data Sheet

Block Number

Unseen Hand	Choice Condition	Chosen Sandpaper	Surprise Scale	Gender